Drying and Rehydration Kinetics of Pasta(Digest_要約)

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論 文 の 要 約

1．題目

Drying and Rehydration Kinetics of Pasta（パスタの乾燥および吸水動力学）

2．要約

PART 1　Drying kinetics of pasta

Chapter 1　Moisture sorption isotherm of durum wheat flour

The moisture sorption isotherms of durum semolina were observed in the temperature range of 30 to 80°C for both the sorption and desorption processes. The isotherms of its constituent starch and gluten were observed at 30°C and that of pasta was observed at 60°C. All the isotherms were well expressed by the Guggenheim-Anderson-de Boer equation. The isotherm for the desorption process lay over that for the sorption one at any temperature, and a slight hysteresis was recognized. Isosteric heats, q, for sorption and desorption processes were estimated according to the Clausius-Clapeyron equation as a function of the moisture content of durum semolina. The q values were larger at lower moisture contents, indicating that water molecules more strongly interact with the wheat flour at lower moisture contents. The q values for the desorption process were greater than those for sorption. The isotherms of starch lay over those of gluten at any water activity, and those of pasta were located between those of starch and gluten.

Chapter 2　Dilatometric measurement of the partial molar volume of water sorbed to durum wheat flour

Moisture sorption isotherms were measured at 25°C for untreated, dry-heated and pre-gelatinized durum wheat flour samples. The isotherms could be expressed by the Guggenheim-Anderson-de Boer equation. The amount of water sorbed to the untreated flour was highest for low water activity, with water sorbed to the pre-gelatinized and dry-heated flour samples following. The dry-heated and pre-gelatinized flour samples exhibited the same dependence of the moisture content on the partial molar volume of water at 25°C as the untreated flour. The partial molar volume of water was *ca*. 9 cm^3/mol at a moisture content of 0.03 kg-H_2O/kg-d.m. The volume increased with increasing moisture content, and reached a constant value of *ca*. 17.5 cm^3/mol at a moisture content of 0.2 kg-H_2O/kg-d.m. or higher.

Chapter 3　Prediction of pasta drying process based on a thermogravimetric analysis

The drying process of durum wheat semolina dough was measured by thermogravimetry in the temperature and relative humidity ranges of 30 to 90°C and 0 to 80%, respectively, in order to predict the drying process of pasta under any drying conditions. About 20% of the water was evaporated during the constant drying-rate period which has been ignored in previous studies. It is demonstrated that the constant drying-rate period should be taken into account in order to predict the drying curve with a high accuracy. The drying rate during the constant drying-rate period and the mass transfer coefficient estimated by the thermogravimetric analysis were expressed as functions of the temperature and relative humidity, and they were useful for predicting the drying processes of pasta under any drying conditions including the programmed ones.

Chapter 4 Thermal analysis of drying process of durum wheat dough under the programmed temperature-rising conditions

The effects of temperature and moisture content on the drying rate of durum wheat pasta were examined using thermogravimetry and differential scanning calorimetry (DSC) at temperature-rising rates of 0.2 to 1.0 °C/min. The activation energy for the mass transfer coefficient of drying was estimated to be ca. 32 kJ/mol at moisture contents of 0.14 kg-H_2O/kg-d.m. or higher, but increased rapidly as the moisture content dropped below this level. The conclusion temperature of the endothermic peak in the DSC and the temperature of the inflection point of the drying characteristics curve were located near the glass transition curve of the durum semolina flour.

Chapter 5 Shrinkage and tensile stress of sheet-like and cylindrical pastas with various moisture contents

The shrinkage of sheet-like and cylindrical pastas of different moisture contents and distributions was measured. A slight anisotropy in shrinkage was observed for both the pastas. The shrinkage ratio of the height to the width directions for the sheet-like pasta slightly depended on the drying conditions and was 0.93 to 0.96. The shrinkage coefficient in the longitudinal direction scarcely depended on the moisture content and was 0.23 for the cylindrical pasta. Although the shrinkage coefficient in the diametric direction for both the pastas was 0.21 at moisture contents higher than 0.17, the coefficient increased for the moisture contents lower than 0.17. The Young's modulus of the dumbbell specimen of pasta did not depend on the drying conditions. However, it decreased with a decrease in the moisture content and became almost constant at the moisture contents lower than 0.17. These facts suggested that glass transition significantly affected mechanical properties of pasta.

PART 2 Rehydration kinetics of pasta

Chapter 6 Estimation of the gelatinization temperature of noodles from rehydration curves under temperature-programmed heating conditions

A novel method in which the rehydration curve is observed under linearly temperature-raising conditions was proposed to estimate the gelatinization temperature of starch-containing foods; it was applied in an estimation of the gelatinization temperatures of dried noodles. The gelatinization temperatures of two kinds of pasta, dried at high and low temperature, were 52.3 and 53.1°C, and those of udon, kishimen, juwari-soba, hachiwari-soba, so-called common soba, Malony®, and kuzukiri were 57.0, 57.8, 61.1, 59.6, 57.4, 48.4, and 49.1°C. The gelatinization temperatures estimated by the method were between the onset and peak temperatures obtained by differential scanning calorimetric measurement.

Chapter 7 Rehydration kinetics of pasta at different temperatures

The rehydration kinetics of pasta was measured in the temperature range of 20-90°C to investigate the temperature dependencies of an equilibrium moisture content and an initial rate of rehydration. The dependencies indicated the mechanism of rehydration: the equilibrium moisture content is limited by the state of starch gelatinization and the initial rate of rehydration is governed by the water diffusion through the pores of the pasta regardless of the starch gelatinization. The empirical equations were proposed to predict the amount of loss of the pasta mass during rehydration which results in the quality loss of cooked pasta and the moisture content which affects the mechanical properties and an optimal rehydration time. The equation of the moisture content, taking the effect of starch gelatinization into consideration, has the initial diameter of pasta, rehydration time, and temperature of rehydrated water as parameters to predict under any conditions.

Chapter 8 Effect of salts on rehydration kinetics of pasta

The rehydration kinetics of dried pasta were measured in the 20-90°C range in 1.83 mol/L of NaCl and at 80°C in 1.83 mol/L of LiCl, KCl, NaBr, and NaI solutions in order to elucidate the role of salt in the kinetics. At the temperatures higher than 70.8°C, the change in the enthalpy of rehydration, DH, in the 1.83 mol/L NaCl solution was 33.1 kJ/mol, which was greater than the DH value in water, and the activation energy for the rehydration, E, in the salt solution was 25.6 kJ/mol, which was slightly lower than the E value in water. The Hofmeister series of ions was an index for their effect on the equilibrium amount of the rehydrated solution of pasta. The apparent diffusion coefficient of water into pasta was not correlated with the crystal radius of the salts, but was with the Stokes radius of the hydrated ions. Equations were formulated to predict the amount of rehydrated solution under any condition of temperature and NaCl concentration.

Chapter 9 Rehydration kinetics of pasta prepared under different drying conditions

The drying conditions of pasta affect its properties, such as appearance, hardness, and rehydration. The dried pasta is eaten after cooking. In this context, the rehydration kinetics of pasta dried under different conditions was measured at various rehydration temperatures. The pasta was characterized by the maximum temperature during the drying: 50°C, 70°C, and 85°C. The rehydration processes of the pasta at any rehydration temperature could be expressed by an empirical kinetic equation of the hyperbolic type, and the equilibrium moisture content and the initial rate of rehydration were estimated, taking the loss of pasta mass during rehydration into consideration. The loss of pasta mass was lower for pasta dried at higher temperature. Maximum temperature affected the change in the enthalpy of rehydration in the temperature region to a greater degree than the gelatinization temperature of starch in the pasta, while it had no effect on the activation energy for the initial rate of rehydration.

Chapter 10 Properties and rehydration characteristics of pasta prepared using various dies

Pasta was prepared using dies made of different materials. The surface was observed using digital and optical microscopes, and was rougher for the pastas prepared using the Teflon, polypropylene, polycarbonate, aluminum, and bronze dies in this order. The extrusion velocity when passing through the die was faster, the bulk density was higher, and the rupture strength was greater for the pasta having the smoother surface. The die material did not affect the gelatinization temperature. The rehydration curves in boiling water containing 0.5% (w/v) sodium chloride were also observed. The curves were expressed by an equation of the hyperbolic type except for the early stage of rehydration in order to estimate the equilibrium amount of water rehydrated based on the bone-dry sample. The momentarily-rehydrated amount of water, which is a hypothetical quantity to characterize the initial water intake, was estimated by fitting the experimental points within 60 s. The amount was higher for the pasta having the rougher surface.

Chapter 11 Measurement of moisture profiles in pasta during rehydration based on image processing

A method using an image processing technique was developed to measure the moisture profile in pasta during its rehydration process. The method is based on the increase in sample color brightness with increasing moisture content. Compared to currently used methods, this method has the advantage that moisture contents around 0.1 kg-H_2O/kg-d.m. can be easily measured at a spatial resolution of 1.6 μm. The moisture profiles obtained by this method suggested that penetration of water into small holes and cracks on the pasta surface, water diffusion in the pasta, and structural relaxation of the protein matrix play important roles in the rehydration mechanism. It was also suggested that starch granule gelatinization prevented water migration into the interior portion of the pasta.

Chapter 12 Effects of relaxation of gluten network on rehydration kinetics of pasta

The aim of this study was to investigate the effects of the relaxation of the gluten network on pasta rehydration kinetics. The moisture content of pasta, under conditions where the effects of the diffusion of water on the moisture content were negligible, was estimated by extrapolating the average moisture content of pasta of various diameters to 0 mm. The moisture content of imaginary, infinitely thin pasta (0-mm durum pasta) did not reach equilibrium even after 1 h of rehydration. The rehydration of pasta made of only gluten (gluten pasta) was also measured. The rate constants estimated by the Long and Richman equation for 0-mm durum pasta and gluten pasta were 7.53×10^{-4} and 7.42×10^{-4} 1/s, respectively, indicating that the rehydration kinetics of 0-mm durum pasta were similar to those of gluten pasta. These results suggest that the swelling of starch by fast gelatinization was restricted by the honeycomb structural network of gluten and the relaxation of the gluten network controlled pasta rehydration kinetics.